

AD-A 101 700

RIA-81-U355

TECHNICAL  
LIBRARY

AD

MEMORANDUM REPORT ARBRL-MR-03096

BURNING RATE OF PRESSED STRANDS OF A  
STOICHIOMETRIC MAGNESIUM-SODIUM NITRATE MIX

Leon J. Decker  
Austin W. Barrows  
J. Richard Ward

March 1981



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND  
BALLISTIC RESEARCH LABORATORY  
ABERDEEN PROVING GROUND, MARYLAND

Approved for public release; distribution unlimited.

DTIC QUALITY INSPECTED 3

Destroy this report when it is no longer needed.  
Do not return it to the originator.

Secondary distribution of this report by originating  
or sponsoring activity is prohibited.

Additional copies of this report may be obtained  
from the National Technical Information Service,  
U.S. Department of Commerce, Springfield, Virginia  
22161.

The findings in this report are not to be construed as  
an official Department of the Army position, unless  
so designated by other authorized documents.

*The use of trade names or manufacturers' names in this report  
does not constitute endorsement of any commercial product.*

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MEMORANDUM REPORT ARBRL-MR-03096	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) BURNING RATE OF PRESSED STRANDS OF A STOICHIOMETRIC MAGNESIUM-SODIUM NITRATE MIX		5. TYPE OF REPORT & PERIOD COVERED Memorandum Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Leon J. Decker Austin W. Barrows J. Richard Ward		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Ballistic Research Laboratory ATTN: DRDAR-BLI Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Armament Research & Development Command U.S. Army Ballistic Research Laboratory ATTN: DRDAR-BL Aberdeen Proving Ground, MD 21005		12. REPORT DATE March 1981
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Director US Air Force Office of Scientific Research Bolling AFB Washington, DC 20392		13. NUMBER OF PAGES 24
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release, distribution unlimited.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Pyrotechnics Combustion Magnesium Sodium Nitrate Fuel-Rich Pressed Propellant		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)      idk, jmk The burning rate of pressed strands made from a stoichiometric mix of magnesium and sodium nitrate was measured in nitrogen over the pressure range 0.1 to 8.6 MPa. A plot of the logarithm of burning rate vs logarithm of pressure reveals two distinct regions with the "slope break" occurring near 2 MPa. At the lower pressures, the slope is 0.3; at higher pressures, the slope is 0.05. The burning rate measured at 3.4 MPa was unchanged when oxygen replaced nitrogen; thus, gas-phase reactions do not affect the burning rate.		

## TABLE OF CONTENTS

	<u>Page</u>
LIST OF ILLUSTRATIONS . . . . .	5
LIST OF TABLES . . . . .	7
I. INTRODUCTION . . . . .	9
II. EXPERIMENTAL . . . . .	9
III. RESULTS AND DISCUSSION . . . . .	11
IV. CONCLUSIONS . . . . .	17
REFERENCES . . . . .	18
DISTRIBUTION LIST . . . . .	19

LIST OF ILLUSTRATIONS

Figure	Page
1. Burning Rate <u>vs.</u> Pressure of Pressed Magnesium-Sodium Nitrate Strands. . . . .	13
2. Burning Rate <u>vs.</u> Pressure of Pressed Magnesium-Sodium Nitrate Strands (Logarithmic Scales) . . . . .	14
3. Burning Rate <u>vs.</u> Pressure for Yellow Flares at 294K. . . . .	16

## LIST OF TABLES

Table	Page
1. SUMMARY OF BURNING RATES AT VARIOUS PRESSURES. . . . .	11
2. BURNING RATES AND DIMENSIONS OF PRESSED STRANDS OF MAGNESIUM AND SODIUM NITRATE . . . . .	12
3. BURNING RATES OF BINARY MAGNESIUM-SODIUM NITRATE MIXES . .	17

## I. INTRODUCTION

Pyrotechnics see frequent military use because they offer light (tracer and illuminating rounds), heat (incendiary rounds), and smoke (obscurants and signaling devices).<sup>1</sup> Although pyrotechnics have recently been tested as propellants (fuel-rich pyrotechnics burn to produce reactive metal vapors),<sup>2-7</sup> studies of their combustion lag far behind conventional propellants.

The studies performed have also focused on the behavior of pyrotechnics near atmospheric pressure. The new role for pyrotechnics as fuel-rich propellants requires higher pressure combustion data starting with burning rates of binary magnesium-sodium nitrate pressed strands. The customary binder was eliminated to simplify interpretation of results, and to provide further data for understanding combustion of propellant candidates. Without the binder, though, burning rate reproducibility suffered.

## II. EXPERIMENTAL

Starting mix for the samples was made from 24.9894g of sodium nitrate (oven-dried and pulverized) and 17.8739g of magnesium (50 mesh, atomized). The ratio of sodium nitrate to magnesium corresponded to a stoichiometric mix according to

<sup>1</sup> "Military Pyrotechnic Series, Part Four, Design of Ammunition for Pyrotechnic Effects," AMC Pamphlet AMCP 706-188, March 1974.

<sup>2</sup> J.R. Ward, F.P. Baltakis, and S.W. Pronchick, "Wind Tunnel Study of Base Drag Reduction by Combustion of Pyrotechnics," BRL Report No. 1745, October 1974. (AD #C016949L)

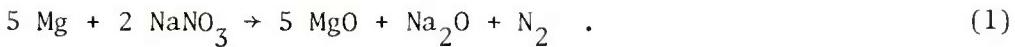
<sup>3</sup> K. Anderson, N.E. Gunner, and R. Hellgren, "Swedish Base Bleeding Increasing the Range of Artillery Projectiles Through Base Flow," Propellants and Explosives, 1, 69 (1976).

<sup>4</sup> K.C. Schadow, "Base Drag Reduction by Combined External Burning/Base Burning," Proceedings of the 1980 JANNAF Propulsion Meeting Vol. I, p. 353, CPIA Publication 315, March 1980.

<sup>5</sup> M.K. King and L.B. Childs, "Development of Highly-Magnesium Loaded Fuel-Rich Propellants," 12th JANNAF Combustion Meeting Proceedings, Vol. III, 201, CPIA Publication 273, December 1975.

<sup>6</sup> M.K. King and J.L. Fields, "Combustion of Highly-Magnesium Loaded Fuel-Rich Propellants," 13th JANNAF Combustion Meeting Proceedings, Vol. IV, 85, CPIA Publication 281, December 1976.

<sup>7</sup> M.K. King, "Combustion Studies of Fuel-Rich Propellants, Atlantic Research Final Report TR-PL-5520, AFOSR Contract No. F44629-71-C00124, August 1976.



The sodium nitrate and magnesium was stirred thoroughly with mortar and pestle.

Pressed strands of magnesium and sodium nitrate for the burning rate determinations were made with a Baird pellet press. Sample preparation started by placing a weighed amount of igniter ("eimite") in one end of the pellet press. A weighed portion of the magnesium-sodium nitrate mix was added and a 33.5 Kn force applied to the mixture for at least two minutes. Considerable trial-and-error was necessary to find force and holding time which would produce strands with uniform density. The pressed strand was removed from the pellet press, weighed, and the dimensions taken. The strands were approximately 4mm x 4mm x 22mm, formed by a pressing pressure of 380 MPa on the strand ( $88\text{mm}^2$  pressing area).

The strands were inhibited with a thick coat of DUCO cement. As with the pressing technique, considerable trial-and-error was spent finding a suitable inhibitor. A thick paste made from DUCO cement and a one-to-one magnesium-sodium nitrate mix was applied to the end of the strand with the igniter. A coil of nichrome wire was included in the paste leaving two 10mm long leads protruding from the paste. The DUCO cement hardened overnight after which the strands were baked at 373K to complete drying. Failure to dry the cement led to uneven burning along the sides of the strands. The strands were conditioned at 294K for the burning rate determinations.

Burning rates were measured in a gas cylinder equipped with two directly opposed viewing ports. The sample was clamped into place on a tray in the gas cylinder and the ignition wires glued to the sample were clamped to wires leading from the ignition power supply. A ruler and an ID card were placed before the sample and photographed with a HYCAM high-speed camera. The ruler and ID card were removed and the sample repositioned if necessary. The gas cylinder was sealed, evacuated, and nitrogen pressuring gas added after the cylinder was isolated from the vacuum line. In one run oxygen was the pressurizing gas. The ignition power supply ignited the sample and turned on the HYCAM camera to photograph the burning strand. The HYCAM camera reaches desired frame speed in four to five milliseconds. Upon completion of the run, the cylinder is depressurized through a "bleed-off" valve and the strand burner readied for the next run.

After the film was developed, the burning rate was determined with a Vanguard motion analyzer. From the picture of the ruler, a correlation between film distance and actual distance was established. Time was determined from timing light exposures focused on the edge of the film. The total distance burned was measured at seven or eight times. The burning rate was taken as the slope of the line drawn through a plot of distance burned versus time.

### III. RESULTS AND DISCUSSION

Table 1 summarizes the mean burning rates and sample standard deviations at the various pressures tested. Table 2 provides the burning rates and dimensions for the individual strands.

TABLE 1. SUMMARY OF BURNING RATES AT VARIOUS PRESURES

<u>Pressure, MPa</u>	<u>Number of Samples</u>	<u>Burning Rate*, g/cm<sup>2</sup>-s</u>
0.10	3	1.9 ± 0.6
.69	3	3.4 ± 0.5
1.72	3	5.7 ± 1.0
3.45	7	5.2 ± 0.6
5.17	7	5.5 ± 0.8
6.89	8	6.0 ± 0.7
8.62	5	6.1 ± 1.0

\*Error given as sample standard deviation.

Figure 1 plots burning rate vs pressure using the data in Table 1 where one sees the burning rate is relatively insensitive to changes in pressure above 2 MPa.

Figure 2 illustrates the fit of the data in Table 2 to

$$r = ap^n \quad , \quad (2)$$

where  $r$  = burning rate,  $\text{g}/\text{cm}^2\text{-s}$ ,  
 $p$  = pressure, MPa, and  
 $a, n$  = constants.

A "slope break" is observed near 2 MPa with a pressure exponent 0.4 in the low pressure region and 0.05 in the high pressure region.

King and Fields<sup>5,6</sup> measured the burning rates of fuel-rich magnesium-teflon, magnesium-HMX-binder, and magnesium-proprietary oxidizer-binder in the same pressure regime. Precise compositions and specifications are classified. The magnesium-teflon exhibited a positive slope break, while the magnesium-proprietary oxidizer had a negative slope break like the magnesium-sodium nitrate mix. The magnesium-HMX propellant burning rate obeyed equation (2) over the pressure range studied.

TABLE 2. BURNING RATES AND DIMENSIONS OF PRESSED STRANDS OF MAGNESIUM AND SODIUM NITRATE

Pressure, MPa	Area, cm <sup>2</sup>	Density, g/cm <sup>3</sup>	Mass, g	Burning Rate, cm/s	Burning Rate, g/cm <sup>2</sup> -s
0.10	0.225	1.93	0.967	0.61	1.2
.10	.215	1.94	.929	1.22	2.4
.10	.228	1.90	.965	1.07	2.0
0.69	0.200	1.95	0.866	1.88	3.7
.69	.174	1.96	.761	1.88	3.7
.69	.218	1.93	.933	1.50	2.9
1.72	0.232	1.95	1.002	2.79	5.4
1.72	.211	1.93	.788	3.66	6.8
1.72	.216	1.86	.917	2.59	4.8
3.45	0.225	1.89	0.944	2.59	4.9
3.45	.190	1.86	.785	3.07	5.7
3.45	.194	1.87	.806	2.97	5.6
3.45	.235	1.97	1.028	2.74	5.4
3.45	.225	1.96	0.983	2.84	5.6
3.45	.235	1.98	1.038	1.98	3.9
3.45	.196	1.97	0.860	2.54	5.0
5.17	0.213	1.97	0.890	2.82	5.6
5.17	.209	1.97	.918	2.21	4.4
5.17	.209	1.89	.880	3.38	6.4
5.17	.208	1.94	.902	2.54	4.9
5.17	.211	1.94	.911	3.02	5.9
5.17	.213	1.97	.935	2.54	5.0
5.17	.181	1.94	.781	3.35	6.5
6.89	0.225	1.88	0.945	3.99	7.5
6.89	.203	1.94	.871	2.56	5.0
6.89	.226	1.92	.962	3.00	5.8
6.89	.243	1.93	1.034	3.28	6.3
6.89	.217	1.95	0.942	2.89	5.6
6.89	.228	1.90	.960	3.30	6.3
6.89	.219	1.93	.937	2.97	5.7
6.89	.243	1.97	1.065	2.87	5.6
8.62	0.216	1.98	0.948	2.66	5.3
8.62	.239	2.00	1.046	2.43	4.9
8.62	.206	1.98	.910	3.12	6.2
8.62	.223	1.93	.950	3.73	7.2
8.62	.224	1.95	.960	3.56	6.9

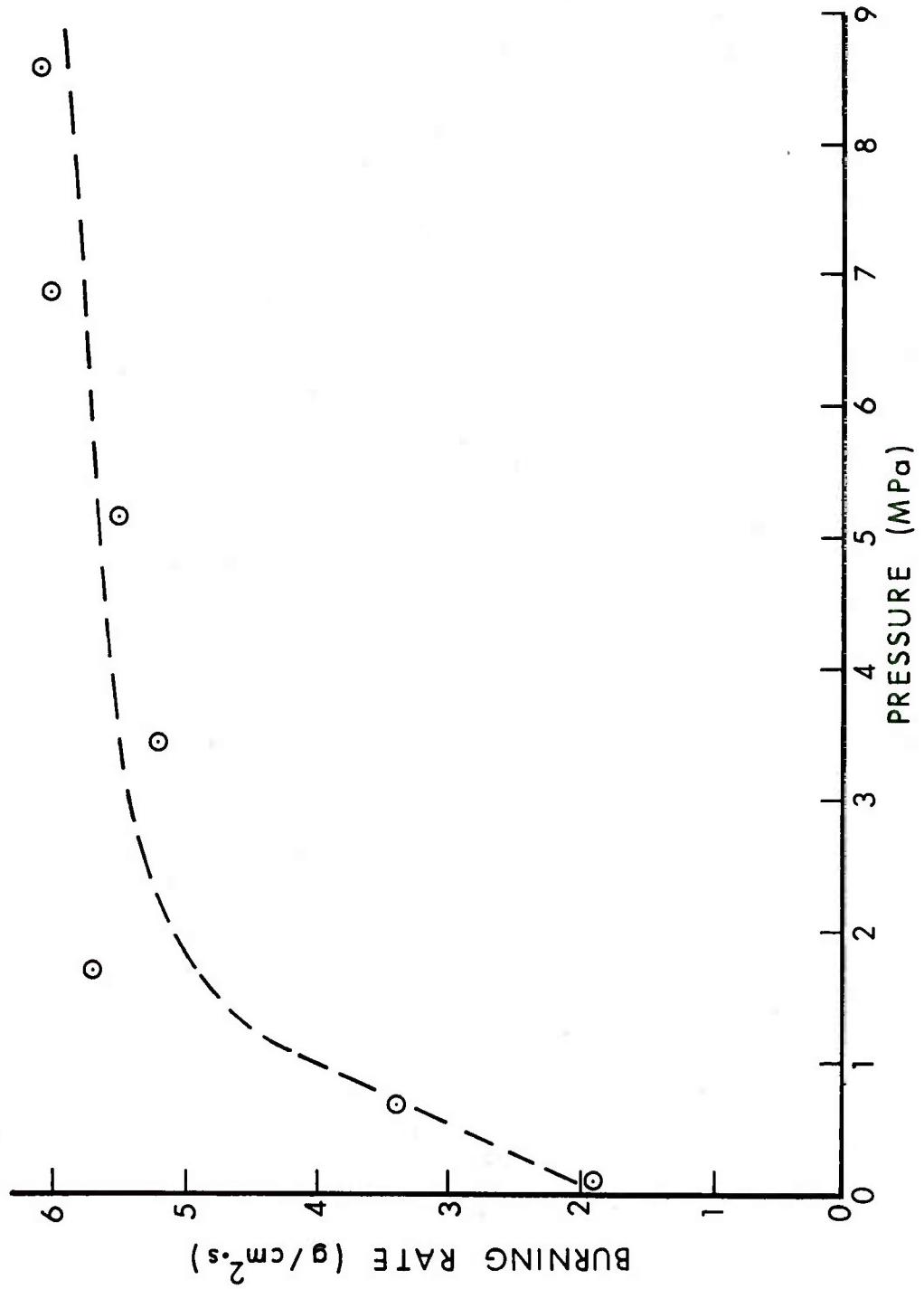


Figure 1. Burning Rate vs. Pressure for Pressed Magnesium-Sodium Nitrate Strands.

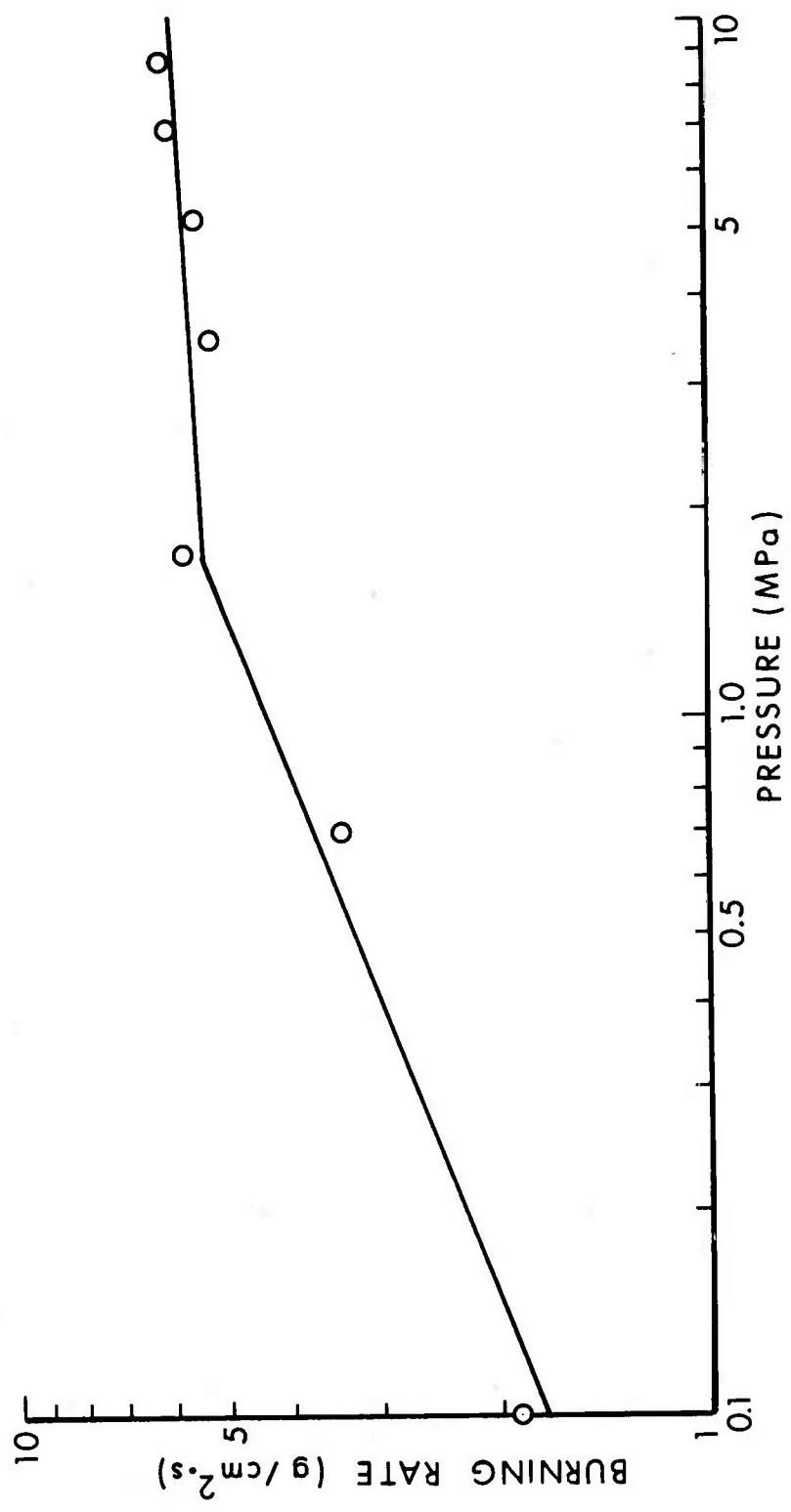


Figure 2. Burning Rate vs. Pressure of Pressed Magnesium-Sodium Nitrate Strand

Other data on the burning rate vs. pressure of pyrotechnic mixes are available at atmospheric and sub-atmospheric pressure.

Rees<sup>8</sup> reported the burning rate of a 30/70 by weight mixture of ferro-titanium metal and barium peroxide fell from 10 m/s at atmospheric pressure to 0.4 m/s at 20 kPa. Rees estimated the pressure exponent as 0.7 for the region 10 to 50 kPa while the burning rate was insensitive to further increase in pressure.

Resnick<sup>9</sup> studied the effect of altitude and temperature on the burning times of flare mixes composed of magnesium, sodium nitrate, and a binder. Figure 3 is a plot taken from Resnick's report of inverse burning time vs pressure plotted on logarithmic scales. The fuel-rich mix, Y-2, has a pressure exponent less than 0.1 in the region near atmospheric pressure, while the nearly stoichiometric mix, Y-1, has an exponent of 0.3 in the same pressure region. The fuel-rich mix also has a larger burning rate at a given pressure.

Resnick's experiments include the effect of the binder. One can show the trends that Resnick observed for flares hold for binary magnesium-sodium nitrate mixes. This can be done by combining the present results with earlier burning rate measurements<sup>10</sup> on fuel-rich, magnesium-sodium nitrate strands (60/40 percent by weight). Table 3 summarizes the burning rates from the earlier tests along with burning rates from the present series of experiments in a common pressure range. One sees the fuel-rich mix burns faster from comparing burning rates at 0.1 MPa. Using data for the 60/40 mix at the only two pressures available gives a pressure exponent of 0.05 between 0.1 and 1.0 MPa. Burning rates for the 60/40 mix were only done at two pressures because the primary purpose of the experiments was to determine temperature sensitivity.

The burning-rate insensitivity to pressure suggests the burning rate is unaffected by gas phase reactions. To test this hypothesis, one strand of the stoichiometric mix was burned in an oxygen atmosphere at 3.45 MPa. The burning rate in oxygen was 5.7 g/cm<sup>2</sup>-s; Table 1 reports the burning rate in nitrogen as 5.2 ± 0.6 g/cm<sup>2</sup>-s suggesting reaction of magnesium with oxygen in the surrounding atmosphere does not affect the burning rate of the pressed strand. This result is consistent with

<sup>8</sup>G.W. Rees, "Non-Gaseous Layer Combustions: Part 2. The Effects of Reduced Pressure and Rotational Motion," Fuel, 52, 226 (1973).

<sup>9</sup>S. Resnick, "Simulated High-Altitude Tests of Illuminating Compositions," Picatinny Arsenal Technical Report No. 2166, April 1955.

<sup>10</sup>R.C. Strittmater, H.E. Holmes, and J.R. Ward, "Sensitivity of Burning Rate to Initial Temperature for a Binary Magnesium-Sodium Nitrate Mix," BRL Memorandum Report No. 02889, December 1978. (AD #A066119)

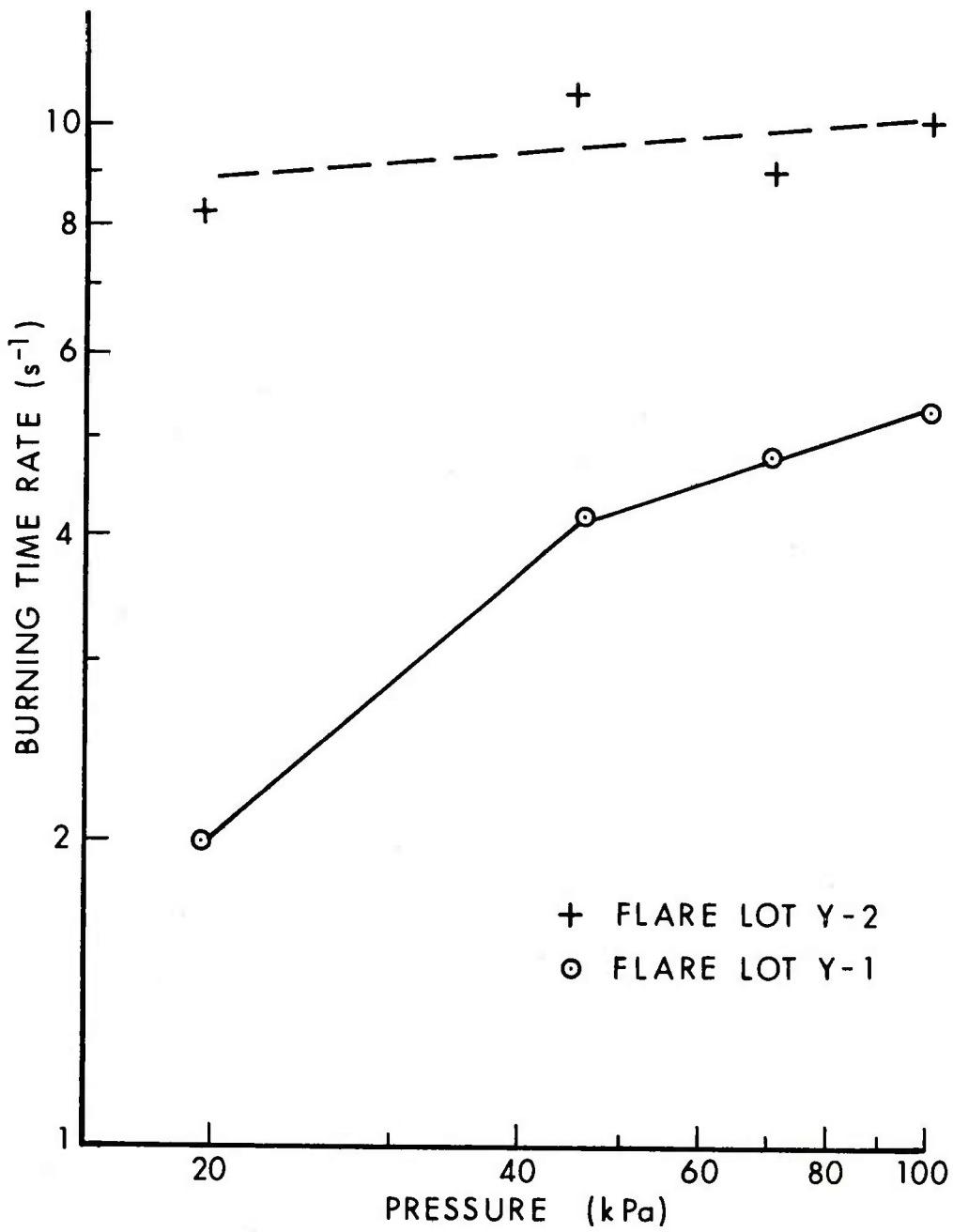


Figure 3. Burning Rate vs. Pressure for Yellow Flares at 294K

TABLE 3. BURNING RATES OF BINARY MAGNESIUM-SODIUM NITRATE MIXES

Pressure, MPa	Burning Rate, g/cm <sup>2</sup> -s	
	Stoich	Fuel-Rich
0.10	1.9 ± 0.6	3.7 ± 0.2
0.69	3.4 ± 0.5	-
1.0	-	4.2 ± 0.1

\* Error given as sample standard deviation.

\*\*Reference 10.

Bond and Jacobs<sup>11,12</sup> who found replacing argon with air had no effect on the decomposition of sodium nitrate-magnesium mixes or on the time to ignition of the same mixes.

#### IV. CONCLUSIONS

1. The burning rate of pressed strands of a stoichiometric magnesium-sodium nitrate mix was measured over the pressure range of 0.1 to 8.6 MPa. The burning rate increases with pressure from 0.1 MPa to 2 MPa above which the burning rate is insensitive to pressure.
2. The burning rate determined in a pure oxygen atmosphere at 3.45 MPa was the same as the rate determined in nitrogen at the same pressure.
3. The burning rate of strands made from a fuel-rich mix of magnesium-sodium nitrate was nearly twice as fast as that of the strands prepared from the stoichiometric mix.
4. A plot of burning rate vs pressure on logarithmic scales for the stoichiometric mix exhibited a "slope break" near 2 MPa. The slope of the line in the low pressure region was 0.4; in the high pressure region, the slope was 0.05. The fuel-rich magnesium-sodium nitrate mix had a slope of 0.05 over the 0.1 to 1.0 MPa pressure range, suggesting that the higher magnesium content reduces the slope-break pressure as well as increases burning rate.

<sup>11</sup> B.D. Bond and P.W.M. Jacobs, "The Thermal Decomposition of Sodium Nitrate," *J. Chem. Soc. A*, 1265 (1966).

<sup>12</sup> B.D. Bond and P.W.M. Jacobs, "Chemical Reaction and Ignition in Mixtures of Magnesium and Sodium Nitrate," *Comb. and Flame*, 10, 349 (1966).

## REFERENCES

1. "Military Pyrotechnic Series, Part Four, Design of Ammunition for Pyrotechnic Effects," AMC Pamphlet AMCP 706-188, March 1974.
2. J.R. Ward, F.P. Baltakis, and S.W. Pronchick, "Wind Tunnel Study of Base Drag Reduction by Combustion of Pyrotechnics," BRL Report No. 1745, October 1974. (AD #C016949L)
3. K. Anderson, N.E. Gunners, and R. Hellgren, "Swedish Base Bleed-Increasing the Range of Artillery Projectiles Through Base Flow," Propellants and Explosives, 1, 69 (1976).
4. K.C. Schadow, "Base Drag Reduction by Combined External Burning/Base Burning," Proceedings of the 1980 JANNAF Propulsion Meeting, Vol. I, p. 353, CPIA Publication 315, March 1980.
5. M.K. King and L.B. Childs, "Development of Highly-Magnesium Loaded Fuel-Rich Propellants," 12th JANNAF Combustion Meeting Proceedings, Vol. III, 201, CPIA Publication 273, December 1975.
6. M.K. King and J.L. Fields, "Combustion of Highly-Magnesium Loaded Fuel-Rich Propellants," 13th JANNAF Combustion Meeting Proceedings, Vol. IV, p 85, CPIA Publication 281, December 1976.
7. M.K. King, "Combustion Studies of Fuel-Rich Propellants," Atlantic Research Final Report TR-PL-5520, AFOSR Contract No. F44629-71-C-0124, August 1976.
8. G.W. Rees, "Non-Gaseous Layer Combustions: Part 2. The Effects of Reduced Pressure and Rotational Motion," Fuel, 52, 226 (1973).
9. S. Resnick, "Simulated High-Altitude Tests of Illuminating Compositions," Picatinny Arsenal Technical Report No. 2166, April 1955.
10. R.C. Strittmater, H.E. Holmes, and J.R. Ward, "Sensitivity of Burning Rate to Initial Temperature for a Binary Magnesium-Sodium Nitrate Mix," BRL Memorandum Report No. 02889, December 1978. (AD #A066119)
11. B.D. Bond and P.W.M. Jacobs, "The Thermal Decomposition of Sodium Nitrate," J. Chem. Soc. A, 1265 (1966).
12. B.D. Bond and P.W.M. Jacobs, "Chemical Reaction and Ignition in Mixtures of Magnesium and Sodium Nitrate," Comb. and Flame, 10, 349 (1966).

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
12	Commander Defense Technical Info Center ATTN: DDC-DDA Cameron Station Alexandria, VA 22314	1	Commander US Army Armament Materiel Readiness Command ATTN: DRSAR-LEP-L, Tech Lib Rock Island, IL 61299
1	Director Defense Advanced Research Projects Agency ATTN: LTC. C. Buck 1400 Wilson Boulevard Arlington, VA 22209	1	Commander US Army Watervliet Arsenal ATTN: Code SARWV-RD, R. Thierry Watervliet, NY 12189
2	Director Institute for Defense Analyses ATTN: H. Wolfhard R.T. Oliver 400 Army-Navy Drive Arlington, VA 22202	1	Director US Army ARRADCOM Benet Weapons Laboratory ATTN: DRDAR-LCB-TL Watervliet, NY 12189
1	Commander US Army Materiel Development and Readiness Command ATTN: DRCDMD-ST 5001 Eisenhower Avenue Alexandria, VA 22333	1	Commander US Army Aviation Research and Development Command ATTN: DRSAV-E P.O. Box 209 St. Louis, MO 63166
4	Commander US Army Armament Research and Development Command ATTN: DRDAR-LCA, J. Lannon DRDAR-LC, J.P. Picard DRDAR-LCE, R.F. Walker DRDAR-SCA, L. Stiefel Dover, NJ 07801	1	Director US Army Air Mobility Research and Development Laboratory Ames Research Center Moffett Field, CA 94035
2	Commander US Army Armament Research & Development Command ATTN: DRDAR-TSS Dover, NJ 07801	1	Commander US Army Communications Rsch and Development Command ATTN: DRDCO-PPA-SA Ft. Monmouth, NJ 07703
		1	Commander US Army Electronics Research & Development Command Technical Support Activity ATTN: DELSD-L Fort Monmouth, NJ 07703

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
1	Commander US Army Missile Command ATTN: DRSMI-R Redstone Arsenal, AL 35809	1	Office of Naval Research ATTN: Code 473 800 N. Quincy Street Arlington, VA 22217
1	Commander US Army Missile Command ATTN: DRSMI-YDL Redstone Arsenal, AL 35809	1	Commander Naval Sea Systems Command ATTN: J.W. Murrin (NAVSEA-62R2) National Center Building 2, Room 6E08 Washington, DC 20360
1	Commander US Army Natick Research and Development Command ATTN: DRXRE, D. Sieling Natick, MA 01762	2	Commander Naval Surface Weapons Center ATTN: S.J. Jacobs/Code 240 Code 730 Silver Springs, MD 20910
1	Commander US Army Tank Automotive Rsch and Development Command ATTN: DRDTA-UL Warren, MI 48090	1	Commander Naval Surface Weapons Center ATTN: Library Br, DX-21 Dahlgren, VA 22448
1	Commander US Army White Sands Missile Range ATTN: STEWS-DP-AL WSMR, NM 88002	1	Commander Naval Underwater Systems Center Energy Conversion Department ATTN: R.S. Lasar/Code 5B331 Newport, RI 02840
1	Commander US Army Materiel & Mechanics Research Center ATTN: DRXMR-ATL Watertown, MA 02172	2	Commander Naval Weapons Center ATTN: R. Derr C. Thelen China Lake, CA 93555
1	Commander US Army Research Office ATTN: Tech Lib Research Triangle Park, NC 27706	1	Commander Naval Research Laboratory ATTN: Code 6180 Washington, DC 20375
1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL, Tech Lib White Sands Missile Range, NM 88002	3	Superintendent Naval Post Graduate School ATTN: Tech Lib D. Netzer A. Fuhs Monterey, CA 93940

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
2	Commander Naval Ordnance Station ATTN: S. Mitchell Tech Lib Indian Head, MD 20640	1	Calspan Corporation ATTN: E. B. Fisher P. O. Box 400 Buffalo, NY 14211
3	AFOSR ATTN: L. Caveny B.T. Wolfson Bolling AFB, DC 20332	1	Foster Miller Associates, Inc. ATTN: A.J. Erickson 135 Second Avenue Waltham, MA 02154
2	AFRPL (DYSC) ATTN: D. George J.N. Levine Edwards AFB, CA 93523	1	General Electric Company Armament Department ATTN: M.J. Bulman Lakeside Avenue Burlington, VT 05402
1	National Bureau of Standards ATTN: T. Kashiwagi Washington, DC 20234	1	General Electric Company Flight Propulsion Division ATTN: Tech Lib Cincinnati, OH 45215
1	Lockheed Palo Alto Rsch Labs ATTN: Tech Info Ctr 3521 Hanover Street Palo Alto, CA 94304	2	Hercules Incorporated Alleghany Ballistic Lab ATTN: R. Miller Tech Lib Cumberland, MD 21501
1	Aerojet Solid Propulsion Co. ATTN: P. Micheli Sacramento, CA 95813	2	Hercules Incorporated Bacchus Works ATTN: R. Simmons Magna, UT 84044
1	ARO Incorporated ATTN: N. Dougherty Arnold AFS, TN 37389	1	IITRI ATTN: M.J. Klein 10 West 35th Street Chicago, IL 60615
1	Atlantic Research Corporation ATTN: M.K. King 5390 Cherokee Avenue Alexandria, VA 22314	1	AVCO Corporation AVCO Everett Research Lab Div ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
1	Olin Corporation Badger Army Ammunition Plant ATTN: J. Ramnarace Baraboo, WI 53913	1	Brigham Young University Dept of Chemical Engineering ATTN: M. W. Beckstead Provo, UT 84601
2	Olin Corporation New Haven Plant ATTN: R.L. Cook D.W. Riefler 275 Winchester Avenue New Haven, CT 06504	1	California Institute of Tech 204 Karmar Lab ATTN: F.E.C. Culick 1201 E. California Street Pasadena, CA 91125
1	Paul Gough Associates, Inc. ATTN: P.S. Gough P.O. Box 1614 Portsmouth, NH 03801	1	Case Western Reserve Univ. Division of Aerospace Sciences ATTN: J. Tien Cleveland, OH 44135
1	Physics International Company 2700 Merced Street Leandro, CA 94577	3	Georgia Institute of Technology School of Aerospace Engineering ATTN: B.T. Zinn E. Price W.C. Strahle Atlanta, GA 30332
1	Pulsepower Systems, Inc. ATTN: L.C. Elmore 815 American Street San Carlos, CA 94070	1	Institute of Gas Technology ATTN: D. Gidaspow 3424 S. State Street Chicago, IL 60616
2	United Technologies ATTN: R. Brown Tech Lib P.O. Box 358 Sunnyvale, CA 94088	1	Johns Hopkins University/APL Chemical Propulsion Information Agency ATTN: T. Christian Johns Hopkins Road Laurel, MD 20810
1	Universal Propulsion Co. ATTN: H.J. McSpadden 1800 W. Deer Valley Road Phoenix, AZ 85027	1	Massachusetts Institute of Technology Dept of Mechanical Engineering ATTN: T. Toong Cambridge, MD 02139
1	Battelle Memorial Institute ATTN: Tech Lib 505 King Avenue Columbus, OH 43201		

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
1	Pennsylvania State University Applied Research Lab ATTN: G.M. Faeth P.O. Box 30 State College, PA 16801	4	SRI International ATTN: Tech Lib J. Barker D. Crosley D. Golden 333 Ravenswood Avenue Menlo Park, CA 94025
1	Pennsylvania State University Dept of Mechanical Engineering ATTN: K. Kuo University Park, PA 16801	1	Stevens Institute of Technology Davidson Laboratory ATTN: R. McAlevy, III Hoboken, NJ 07030
1	Pennsylvania State University Dept of Material Sciences ATTN: H. Palmer University Park, PA 16810	1	University of Illinois Dept of Aeronautical Engineering ATTN: H. Krier Transportation Building, Rm 105 Urbana, IL 61801
1	Princeton University Forrestal Campus ATTN: Tech Lib P.O. Box 710 Princeton, NJ 08540	1	University of Minnesota Dept of Mechanical Engineering ATTN: E. Fletcher Minneapolis, MN 55455
1	Purdue University School of Mechanical Engineering ATTN: J. Osborn TSPC Chaffee Hall West Lafayette, IN 47906	1	University of Southern California Dept of Chemistry ATTN: S. Benson Los Angeles, CA 90007
1	Rutgers State University Dept of Mechanical and Aerospace Engineering ATTN: S. Temkin University Heights Campus New Brunswick, NJ 08903	2	University of Texas Dept of Chemistry ATTN: W. Gardiner H. Schaefer Austin, TX 78712
		2	University of Utah Dept of Chemical Engineering ATTN: A. Baer G. Flandro Salt Lake City, UT 84112

DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>
	<u>Aberdeen Proving Ground</u>
	Dir, USAMSAA ATTN: DRXSY-D DRXSY-MP, H. Cohen
	Cdr, USATECOM ATTN: DRSTE-TO-F
	Dir, USACSL Bldg E3516, EA ATTN: DRDAR-CLB-PA

### USER EVALUATION OF REPORT

Please take a few minutes to answer the questions below; tear out this sheet, fold as indicated, staple or tape closed, and place in the mail. Your comments will provide us with information for improving future reports.

1. BRL Report Number \_\_\_\_\_

2. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

3. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.)  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.)  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: \_\_\_\_\_

Telephone Number: \_\_\_\_\_

Organization Address: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_